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A STUDY OF THE CLERID, THANASIMUS NIGRIVENTRIS LEC., WITH NOTES ON OTHER INSECT ENEMIES OF THE WESTERN PINE BARKBEETLE

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Forest Insect Laboratory
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Introduction

The present method used in the control of the western pine barkbeetle, Dendroctonus brevicomis Lec.--that is, the felling of the infested trees and peeling and burning the bark--while of proven value under many conditions is costly, of limited practical application, and even where immediately successful usually gives only temporary relief. Because of these disadvantages of our present methods, studies were started in 1922 to determine the possibilities of biological control through the use of parasites and predators.

The introduction of beneficial insects from other regions is hardly to be considered in this instance. The western pine beetle is a native insect with a complete associated fauna, including a numbef of predators and probable parasites as well as many secondary insects, scavengers and others of unknown habits. There are probably few areas with a more complete fauna of scolytids and associates than that in which the western pine beetle is found, so that the desirability of establishing exotic species in this association would be questionable even if possible.

Our work has therefore been confined to a study of native species which might be used to supplement direct control operations, the aim being not to discard entirely our present methods, but rather to modify them so as to protect as far as possible the beneficial insects instead of destroying them with our enemy, the western pine beetle.

The present study was started late in 1922 and continued through 1923 in connection with the Southern Oregon-Northern California Control Project, under the supervision of Miller and Keen. The studies were discontinued in 1924 and not started again until 1926. During 1926 and 1927 the work was continued as one of the Cascadel studies near Northfork, California.

Parasites

Preliminary studies, which included field observations, rearing all insects from western pine beetle-infested bark, and the shaving up of hundreds of square feet of similar bark, have shown the parasites to be of comparatively little importance, and because of this most of our work has been with the predators. A few parasitic species are almost always found associated with D. brevicomis, but not in sufficient numbers to be of much importance. This applies only to the larval and pupal stages found in the bark. It is possible that there are egg parasites that would work under the bark and of which we know nothing. This possibility will be checked during the 1928 season.

A list of insects of known or suspected parasitic habits, with descriptive notes and what is known of their habits, is given in the following:

Hymenoptera

Roptrocerus spp. There are at least two species of this genus that are commonly found associated with D. brevicomis. Species "a" has been described by S.A. Rohwer as "a greenish-black Pteromalid chalcid with a compressed abdomen and a well exserted ovipositor which is as long as the thorax; legs pale yellow below femora; antennae 13-jointed; wings clear; post-marginal a little longer than stigma and much shorter than marginal; may be same as eastern species."

It is known to be parasitic on the larvae of Ips oregoni (Eich.) and is probably an external parasite on D. brevicomis. The larvae have been found in the pupal cells of Ips oregoni with the remains of the parasitized I. oregoni prepupal larvae. While no actual case of parasitism on D. brevicomis has been reported, this parasite has been observed ovipositing in the bark in crevices or in D. brevicomis ventilation holes on yellow pines heavily infested with this scolytid; and it has been reared from yellow pine bark which was infested with D. brevicomis and no other scolytid.

Another species determined by Rohwer as belonging to this genus (Roptrocerus) is apparently an internal parasite. It was observed by J.E. Patterson (unpublished) while ovipositing in a Dendroctonus monticolae Hopk. larva, exposed when the bark was stripped from an infested sugar pine. This species is found associated with D. brevicomis and has been reared from D. brevicomis-infested bark.

Cecidostiba burkei Cwfd. is also commonly associated with the western pine beetle in much the same way as Roptrocerus spp. The following notes on this species are given by Rohwer: "Description--an elongate Pteromalid chalcid with pointed, compressed abdomen which is much longer than the head and thorax; antennae slender; legs slender, mostly yellowish below the femora; body greenish with bronzy reflections; wings clear; the post-marginal vein much longer than the marginal; mesopleurae without a smooth, shining area. Host: Dendroctonus pseudotsugae Hopk., Ips confusus (Lec.) and D. brevicomis (?). Not positively associated with D. brevicomis, though it has been observed ovipositing in yellow pine bark infested by this species and has been reared from bark containing this species. Notes by Champlain state that it is a larval parasite which does not spin a cocoon."

Patterson under Hopk. number 15726ax reports it as a parasite of D. monticolae. He collected the C. burkei adults from the pupal cells of the scolytid found with the remains of the host. It is not known whether it is an internal or external parasite.

Eurytoma sp. has been found ovipositing in D. brevicomis-infested bark. It may or may not be parasitic, as the species of this genus vary from parasitic to phytophagous.

Diptera

Medeterus aldrichi (Wheeler) was noted by Miller (unpublished) as an external parasite of *D. monticolae*, and may be parasitic on very young *D. brevicomis* larvae. This species is found only between the wood and the bark, and so could not be parasitic on the larvae after they have worked out into the bark. It is probably of most importance as a parasite of *D. monticolae*, *D. ponderosae*, Ips. spp. and other barkbeetles which complete their development between the wood and the bark.

As part of the 1928 studies on the Modoc area it is planned to do some work on the parasites of *D. brevicomis*, especially to determine the feeding habits of some of the above species and their importance in the natural control of the western pine beetle.

Predators

Coleoptera

Although there is a large number of beetles associated with *D. brevicomis* that vary from the typically predaceous to the doubtfully predaceous, only two were found to be of real importance in the control of this scolytid. An important limitation on the number of effective predators is the fact that the *D. brevicomis* larvae start boring out into the bark immediately upon hatching. Because of this habit only those predators that are barkboring forms can follow the broods and prey upon them.

This narrows the list of insect predators on *D. brevicomis* broods down to the black-bellied clerid (*Thanasimus nigriventris* Lec.), the green ostomid (*Temnochila virescens* (Fabr.) var. *chlorodia* (Mann.)) and to a limited extent the Colydiid (*Aulonium longum* Lec.) Of the other predators found on infested yellow pine the red-bellied clerid (*Enoclerus sphegeus* (Fabr.)) is occasionally predaceous on the western pine beetle adults, but never on the broods. It is normally predaceous on *D. ponderosae*, *D. monticolae* and other barkbeetles that complete their development beneath the bark. *Othnius umbrosus* Lec., another clerid, is a predaceous species, but has never been reported as feeding on *D. brevicomis*. In the larval stage it is known to be predaceous on *I. oregoni* broods. *Cucujus clavipes* var. *puniceus* Mann.) is predaceous in both the larval and adult stages, but is seldom found associated with *D. brevicomis*. It is a common enemy of termites and secondary beetles in trees that have been killed and abandoned by the western pine beetle. *Deretaphrus oregonensis* Horn. is a predaceous colydiid occasionally found with *D. brevicomis* but never reported as one of its predators. Keen[1] reports it as predaceous on some of the cerambycid and buprestid larvae. There are three or four species of colydiids of the genus Lasconotus which are found beneath the bark of D. brevicomis-infested yellow pine whose habits are not known. They may be predaceous. The Tenebrionid, *Hypophloeus parallelus* Melsh., the Histerid, *Plegaderus nitidus* Horn, and the Staphylinids, *Phloeonomus pusillus* (Grav.) and *Nudobius cephalus* (Say) are all found, commonly in *D. brevicomis* egg galleries; but they are not typical predators, are never

found out in the bark, and have never been reported as predaceous on any of the stages of D. brevicomis. They probably act principally as scavengers, though they may feed to a limited extent on barkbeetle eggs and very small larvae that are found under the bark. Ralph Hopping, in an unpublished "Manual of Insect Control for California" reports certain undetermined staphylinids as feeding on the eggs of some of the scolytids. One of the larger histerids, Platysoma punctigerum Lec., is commonly found in I. oregoni egg galleries, and an adult was found feeding on a living I. oregoni larva by the writer. (See Hopk.No.17012a)

Aulonium longum Lec. larvae have been found feeding on D. brevicomis larvae and pupae in a few instances, and this species may be considered occasionally predaceous. However, unsuccessful attempts to get either the larvae or the adults to feed on any of the stages of D. brevicomis, together with observations on this species in the field for the last five summers, have convinced the writer that this insect is not typically predaceous, and in any case is of little importance in the natural control of the western pine beetle. This stand is supported by the work of Dr. Craighead, who reared A. longum from small larvae to adults without living insect food of any kind, and who found that this species does not have the predaceous type of mouth parts.

Other Predators

There are a number of insects of other orders that are more or less predaceous on the western pine beetle.

Rhaphidia oblita Hagen is a neuropteroid species with predaceous habits, at least in the larval stage. It is commonly associated with D. brevicomis on infested yellow pine, but has never been known to feed naturally on this scolytid. The writer was able to get the large R. oblita larvae to feed on small D. brevicomis larvae, but they were not able to feed on the larger larvae. They feed naturally on small dipterous larvae beneath the bark of infested trees. Essig (1) reports them as predaceous on various stages of barkbeetles and other wood-boring insects.

Attempts to force the adults to feed on any of the stages of D. brevicomis were unsuccessful. This species is probably of little importance in the natural control of the western pine beetle.

Large black ants of the genus Camponotus and the large red ants, Formica haemorhoidalis, have frequently been known to capture D. brevicomis adults and carry them away to their nests, and where abundant they may be a factor in natural control.

Mites, pseudoscorpions, birds, and certain fungi and bacteria might be included with the natural biotic ~~features~~ factors affecting the control of the western pine beetle, but they will not be considered here.

Graphisurus spectabilis (Lec.) and probably other bark-feeding cerambycids, while not predaceous insects, are probably more important indirectly than many of the true predators. They feed on the inner bark and so rob the small D. brevicomis larvae of their food, and probably accidentally kill outright a large number of the larvae while feeding.

Preliminary studies show that G. spectabilis may be quite important in reducing the D. brevicomis broods. Fig. 1 shows the effect of this cerambycid on the emergence of the western pine beetle. It is based on the examination of 34 square feet of bark from four trees near Northfork, Calif. This shows an emergence of 60 D. brevicomis per square foot from the sections with little cerambycid work, and an emergence of 37 per square foot where a large proportion of the inner bark had been destroyed by the cerambycids. Since these sections were taken from the same trees and selected solely on the basis of the amount of cerambycid work shown on the inner bark, this difference in the emergence is quite significant.

There remain only two insects as important predaceous enemies of the western pine beetle--Thanasimus nigriventris and Temnochila virescens var. chlorodia. As most of our work has been on the clerid, the ostomid will be disposed of first, and the balance of the paper will be devoted to T. nigriventris.

Temnochila virescens var chlorodia

While no complete study of this ostomid has been made, a number of notes were taken on its life history and habits in connection with the studies on T. nigriventris. Most of the following observations were made near Klamath Falls, Oreg., in 1923.

Egg Stage

The eggs are usually laid under the bark scales along the sides of bark crevices, where the adults are commonly found. However, they are frequently discovered under the outermost bark scales in the same situations in which T.n. eggs are laid. The eggs are about .07"-.09" in length and .017"-.02" in diameter at the largest point and taper slightly toward each end. They are sub-cylindrical in shape and have no surface markings. They are opaque white when first laid, becoming semi-transparent for the anterior 1/8 and the posterior tip before hatching. As many as 30 have been found in one mass, closely fitted into a mat of one layer in thickness. The number of eggs laid by each female is not known, but it is certainly over 30 and probably two or three times this number. The incubation period is around 14 days under average conditions.

Larval Stage

The hatching of a larva was observed on August 9; the first indication was the movement of the new larva in the egg, causing a bending motion of the whole egg. This continued intermittently until the anterior end of the shell broke open on the lower side. Through this opening the larva gradually worked its body. When first hatched it was all a semi-transparent white except the tips of its mandibles, which were a dark brown. It was slightly over 1/16" in length.

After hatching the larvae work their way through to the inner bark, taking advantage of cracks between the bark scales and the entrance and ventilation holes of the D.b. After reaching the inner bark they begin to feed on the young D.b. larvae, following them as they work back into the middle of the bark. They develop with the D.b. and feed upon the larvae, pupae and new adults while still in the larval stage. They burrow their way through the bark at will, going from one D.b. to the next while feeding.

Only the larvae which hatch by July 1 complete their development during one season at Klamath Falls. Of a large number of larvae followed through from the latter part of June and first part of July to the middle of September only a few reached the adult srage, while many of them at that time were still only partly-grown larvae. These overwinter and pupate in the spring. The larval period varies from about three or four months for those that complete their development in the one season to ten or eleven months for those that overwinter as larvae.

Pupal Stage

The pupal stage is passed in an unlined cell in the middle or outer bark at the place where the larva finished feeding (Fig.2). There is evidently no larval migration such as is found among the clerids. The pupal stage of the individual lasts about two weeks--10 to 20 days, av. about 14.

Adult Stage

The adults emerge a few days after changing from the pupal form. They are usually found in the crevices of the bark, though they may be seen crawling about on the bark at times. They are not nearly so active as the clerids, and catch their prey by stealth. Unfortunately they do not confine their feeding to the D.b. adults, and probably feed on any insect they can capture. On August 8 a T.v c. adult was observed while it killed and partly consumed a T.n. adult. The T.v c. first seized the clerid with its mandibles at the juncture of the head and thorax; it then used its front legs and at times the middle pair to hold its victim against the bark while it fed upon the internals. They are also cannibalistic in the larval stage.

The average adult life of a T.v c. is about four months for those that do not overwinter, and about 10 to 12 for those that do. The adults overwinter in the bark crevices of infested trees.

Results of Cage Experiment with T.v.c.

Of 28 adults caged June 23, 15 were still alive on September 17. This shows an average life of over three months when caged.

During this period D.b. adults were fed to the T.v.c. and a check kept on the number eaten during two 2-week periods. It was found that on an average a T.v.c. adult ate .935 D.b. adults per day.

It was found possible to secure oviposition by the T.v.c., and larvae to about half-grown were reared in the infested bark sections that

Thanasimus nigriventris Lec.

Introductory

This clerid was selected for intensive study because the preliminary work done on the predaceous insect enemies of the western pine beetle show that it is by far the most important. It is probably less prolific and less voracious than the ostomid, but it is approximately four times as abundant on infested yellow pine, the adults are more active and so better adapted to preying on the *D. brevicomis* adults, and in the western yellow pine belt of California and southern Oregon it feeds almost exclusively on this scolytid. The ostomid will feed on almost any of the insects found on infested yellow pine, including beneficial insects, and is even cannibalistic in the larval stage; but *T. nigriventris* is closely associated with *D. brevicomis* in all stages and seldom feeds on other insects (this applies only to western yellow pine stands).

Most of the work done prior to 1927, including observations by other western workers in forest entomology, has been covered in three unpublished reports by the writer, (Person (1),(2),(3) but it was thought advisable to bring together the more important observations from the earlier reports, and by adding to them the results of the 1927 studies bring our knowledge of the subject up to date in a single report. The principal reason for doing this at the present time is that the studies at Cascadel, where most of our work on the clerids has been done, are to be discontinued, and the center of work transferred to the Modoc National Forest for the 1928 field season.

The *T. nigriventris* studies will be considered under three headings. The first deals with the biology of the insect, especially its life history and habits in their relation to *D. brevicomis*; the second treats of its importance as a natural control factor, and the third shows how our knowledge of the habits of this beetle may be applied in improving our artificial control methods.

Life History and Habits

Historical

Thanasimus nigriventris was described in 1861 by John L. LeConte (1) from specimens collected near Fort Colville in northeastern Washington and from the Bitterroot Valley, Montana. He refers to it as a species of coleoptera inhabiting the Pacific district of the United States. Its range is probably coextensive with that of the western yellow pine, including the var. *scopulorum*, and according to Champlain (1) it has been reported from Michigan and Wisconsin. Trimble (1) also reports it on *Pinus radiata* in the central coast region of California; and Chamberlin has collected it in the Willamette Valley of Oregon on Douglas fir and grand fir. Chamberlin also has adults which he collected in Arizona and in the Sandia Mountains of New Mexico.

The clerids in general are well-known throughout the world as important predators, and there is a considerable amount of literature on many of the species, but little has been published on T. nigriventris. Champlain (1) in 1921 summarized the notes of Webb, Hopkins, Fiske, Burke and Champlain, which are found in the office of the Forest Entomologist, Bureau of Entomology. He reports the adults as predaceous on Ips, Pityophthorus and Dendroctonus. The feeding of an adult on an adult D. ponderosae is also described and a few life history notes are given. He states that the eggs are deposited in the entrance galleries of the host. This does not agree with my observations. Oviposition has been observed a number of times, and literally hundreds of T. nigriventris eggs have been found on yellow pine infested with D. brevicomis. In every case the eggs were deposited beneath the outer bark scales and in no case were they ever found in the entrance galleries. It may be found that this clerid varies its egg-laying habit with the barkbeetle with which it is associated.

While Hopkins has never published on T. nigriventris, he has written a number of articles on both Thanasimus dubius Fabr., a common eastern clerid, and the European barkbeetle destroyer, Thanasimus formicarius (Linn.), which he introduced from Europe in an attempt to control D. frontalis and some of its associates. The feeding habits of both these clerids are evidently about the same as those of T. nigriventris. The feeding habit of the adult is well illustrated in Bulletin 83--Barkbeetles of the Genus Dendroctonus (p.71) by Hopkins (1)--and described in an article in the Canadian Entomologist in 1893 (Hopkins 2).

A more recent reference to T. nigriventris is in an article by F.M. Trimble (1), in which he reports this clerid as one of the natural enemies of Ips radiatae Hopk. and Ips plastographus Lec. in the Monterey pine area of the central coast region of California. This is the only record we have of T. nigriventris on P. radiata.

Keen (1) in a recent publication reports T. nigriventris as the most active enemy of the western pine beetle (D. brevicomis). Other REFERENCES TO T. nigriventris are found in the unpublished notes of Miller, Keen, Burke, Patterson and Person at the Palo Alto (Calif.) station of the Bureau of Entomology, Office of Forest Insect Investigations. Mr. Edmonston, also of the Bureau of Entomology, found T. nigriventris very abundant near Prescott, Ariz., where it was associated with D. barberi, D. approximatus, D. convexifrons and D. arizonicus. Dr Van Dyke of the University of California gave material assistance in the search of literature, and also offered a number of observations on T. nigriventris and the other predators noted.

Miller reported the adults as predaceous on D. brevicomis near Ashland, Oreg., in 1914. Since then Patterson, Keen, Burke, Wagner and Sargent, as well as the writer (all of the Bureau of Entomology) have reported this insect as associated with D. brevicomis and in a number of cases actually feeding on this scolytid.

In the article by Boving and Champlain (1) previously referred to, Boving described a large number of clerid larvae, but because of a lack of authentic material the larva of *T. nigriventris* was not described. The writer sent some larval material to Boving in 1923, and he has kindly agreed to write a description of the larva to be included in a later article. In general the size and color agree with the larva of *T. dubius*, but it differs in the size and shape of the cerci and cerci plate and probably in other characters.

The following details of its life history and habits were worked out by the writer in the vicinity of Klamath Falls, Oregon, in the summer of 1923, and at Cascadel, at an elevation of 3500 feet, on the Sierra National Forest of California, during 1926 and 1927, supplemented by observations throughout the yellow pine belt of California and southern Oregon during 1924 and 1925. These observations were limited ~~entirely~~exclusively to the association of *T. nigriventris* with *D. brevicomis* on the western yellow pine, *Pinus ponderosa* Lawson.

Oviposition

In searching for a suitable place to oviposit, the female runs nervously about on the bark of an infested tree, stopping frequently to feel under an outer bark scale withthe ovipositor. When a satisfactory place is found the ovipositor is inserted about one-eighth inch into the minute opening between the bark scales, and the eggs are laid. Usually from two to five eggs are laid in a single group, but as many as ten have been found, closely fitted together into a one-layered mat.

Caged clerids oviposited on the outside of the bark with no attempt at concealment; but under natural conditions they are always hidden so that it is necessary to flip off the outer bark scales to find them.

The total number of eggs laid by each female has not been determined, but it is believed that 20 to 50 would be a fair estimate. Eggs are laid during the day, the adults being most active on bright, warm days.

The Egg

The eggs are light pink in color, with a white circular band near the smaller end. The length is between .05 and .07 inches and the width between.014 and .018 inches. The shape is elongate ovoid, with a slightly curved longitudinal axis and a more gradual taper toward the smaller end. There are no surface markings. (See Figs. 3 and 4)

The incubation period is about 10 to 14 days under average field conditions.

The Larva

When the larva is ready to emerge, it twists about until the egg splits open anterior to the head, and the larva works itself out by continual twisting and bending. The young larvae are pink in color, with the chitinized parts dark brown. After freeing themselves from the eggshell they crawl about on the bark until a suitable crack is found, into which they disappear.

Within a short time they work their way through the bark, taking advantage of cracks and the ventilation holes of the western pine beetle, and are next found in the phloem, or inner bark. Here they begin feeding on the newly-hatched D. brevicomis larvae. As the latter develop they work out toward the outer bark, where they finally pupate. The clerid larvae work outward with them, boring their way from one larval tunnel to another, killing and consuming a part or all of the victim, except the chitinized parts. They feed readily on the D. brevicomis larvae and pupae and occasionally on a newly-formed adult, but will not feed on the adults after the chitinized parts have started to harden.

By the time the D. brevicomis brood has completed development, most of the clerid larvae have reached the mature larval stage. A variable percentage, usually from 40 to 90, of these clerid larvae bore out through the bark and crawl to the base of the tree. Here they either pupate in the outer bark scales near, either a little above or a little below, the surface of the ground, or in the ground or in sticks or pieces of bark in the duff, usually above the mineral soil. The other 10 to 60 per cent pupate in the outer bark scales near where they stopped feeding.

The prepupal larvae hollow out flattened ovoid cells and line them with a white, silvery substance. These cells are quite characteristic, and are easily distinguished even after the clerids have emerged from them (see Fig. 5).

The larval stage of the individual is between 30 and 60 days for those developing during the summer, and from 5 to 7 months for those that overwinter. The pupal period of the individual is about 6 to 14 days.

The Adult

The adults emerge within a few days after completing their development and are ready to fly to a newly-attacked D. brevicomis tree.

They are found running about on newly-attacked living trees, windfalls or slash, where they capture and feed upon the attacking barkbeetles, mate and lay their eggs.

Feeding Habits of Adult

As the adult clerids like the sunlight and usually feed in the open, their feeding habits are easily studied. The clerid moves about very rapidly over the bark, and when it encounters a barkbeetle it seizes the victim with its four anterior legs, balancing itself on its two posterior legs and the tip of the abdomen. Regardless of the position of the scolytid when captured, the clerid always turns it so that their venters are opposed and their heads facing in the same direction. The point of attack is usually at the juncture of the head and thorax or of the thorax and abdomen. Feeding habits are similar to C. formicarius (see Hopkins (1)). The amount of the beetles actually consumed varies from a small part of the soft internals to practically all the body except the wings and the more heavily-chitinized parts.

Feeding experiments were conducted to determine the "beetle-day" consumption of T. nigriventris in comparison with other predators of D. brevicomis adults under caged conditions.

Large glass jars containing pieces of yellow pine bark were used for the study.

A number of T. nigriventris and D. brevicomis were put in one of these jars and a count made of the total number of D. brevicomis killed and at least partially eaten. From these studies it was found that the "beetle-day" consumption of the clerids was .66.

From field observation it appears that this is a conservative figure.

The life of caged adults averaged about 40 days, so that under natural conditions the adults would probably live about two months.

Life History

The life history of T. nigriventris was worked out in its relation to that of D. brevicomis. It is quite complicated because of the overlapping of generations, so that it could not be satisfactorily worked out in the one summer spent in southern Oregon. At Northfork the life history was followed for two years, so that a satisfactory life history chart has been worked out (see Fig. 6). The principal method used in working out the life histories was to locate a number of trees when first attacked and follow the development of the broods by shaving up sample sections of bark at frequent intervals and noting the stage of both D. brevicomis and the clerids. Locating newly-attacked trees was simplified by caging the lower trunk of certain trees and forcing attacks into these caged sections. This usually attracted beetles to the uncaged part of the trunk and a normal development followed. The brood development in these sample trees was checked with a large number of observations on other trees, many of which were felled to make possible the bark analysis of the entire trunk. This chart shows the rate of development of T. nigriventris broods for each of the three D. brevicomis generation trees for 1926 and 1927.

It was found that there are three fairly distinct generations of D. brevicomis at Northfork. The D. brevicomis life history is shown in broken lines and that of the clerid in solid lines. It may be seen that while the D. brevicomis adults emerging from the first-generation trees make the second-generation attack in July and August, and the emerging adults from the second-generation D. brevicomis trees make the third-generation attack in September and October, this is not true of the clerids. The development of the clerids is so much slower that only a very few of the brood on the first-generation trees emerge in time to lay their eggs on the second-generation D.b. trees, the largest percentage attack the third-generation trees, and a small percentage of clerids from the first-generation trees overwinter as prepupal larvae at the base of the trees, and do not emerge until the following spring.

On the second-generation D.b. trees only a small percentage of the clerids emerge in time to lay their eggs on the third-generation D.b. trees. About 80 to 90 per cent of the clerids overwinter as prepupal larvae and emerge the following spring. Both the D. brevicomis and the clerid broods overwinter as eggs or larvae in the third-generation D. brevicomis trees, but the clerids emerge a month or two later the following year.

It is evident from the above that while there are three fairly distinct generations of D. brevicomis, there are not more than two generations of T. nigriventris at Northfork, Califl

Figure 7 is a quantitative graph of the life history for the clerids on the 1926 D.b. trees. It shows roughly the peaks for the diffesent stages, the relative importance of the partial broods and the abundance of the clerids on the three D. brevicomis generation trees. This last point will be discussed later to show its importance in artificial control operations. Fig. 7A shows the comparative abundance of different stages of T. nigriventris for Generations II and III, 1926.

Of course the rate of development for both D. brevicomis and T. nigriventris would vary in different localities, and for different seasons in the same locality. It will be noted that the broods were later in 1927 than in 1926 at Northfork, no doubt due to the cold spring of 1927.

In the Klamath Falls region of southern Oregon, D. brevicomis has only two or two and one-half generations at the most, and the T. nigriventris generations are correspondingly reduced.

Importance of T. nigriventris in the Natural Control of D. brevicomis

The object of this part of the study was to determing by quantitative methods the effect of T, nigriventris on the D. brevicomis broods under natural conditions.

Procedure

The field studies were carried on in connection with caging experiments with D. brevicomis on resistance and attraction. In this work from 15 to 20 feet of the base of six yellow pine trees were caged and an attack started by introducing D. brevicomis adults into these cages. The cages were four feet square and built of surfaced 2x4 material covered with 16- or 18-mesh wire screen. The screen was tightly fitted on all the seams and around the trunk of the tree above the frame, so that the caged D. brevicomis could not escape, nor could other insects get into the caged part of the tree (see Fig. 8). The trees used were between 20 and 30 inches in diameter and fsom 100 to 140 feet in height.

The attack was started on the three trees used in 1926 and one of the trees used in 1927 by putting yellow pine bark infested with D. brevicomis new adults in the cages. As the beetles emerged they attacked the trees, since the cage kept them from escaping. It was found that the emergence of D. brevicomis from this infested bark was completed and the trees killed before the emergence of the predators. Taking advantage of this fact, all the bark was removed from the cages as soon as most of the D. brevicomis had emerged, and the caged part of the tree was kept practically free from clerids; while the part of the tree above the cage was exposed to the normal action of both D. brevicomis and the clerids. In the other two cages only the D.b. adults collected from rearing cages were used, so that these two cages were kept entirely free from predators. Then by comparing the number of clerids and the number of D. brevicomis at different stages in their development in sample areas just inside the top of the cage with similar areas just outside the top of the

cage, it was possible to determine the effect of the clerids, at least roughly. The study of these six trees was supplemented with bark counts and observations from a number of other trees, both caged and uncaged, but especially from trees that were attacked naturally.

The development of the broods within the bark was followed by carefully shaving up and examining the contents of sample areas of the bark. These brood counts were made at three different stages. The first count was made when the D. brevicomis broods were in the small larval stage, the second count at the prepupal larval stage, and the third count shortly after the D. brevicomis had emerged, at which time T.nigriventris would be in the mature larval stage. On some of the trees the first count was not made. For the first count usually only one square foot of bark was used inside and one square foot above the cage. For the other two counts, strips one foot in width and extending completely around the trunk were shaved up, one inside and one above the cage.

All the samples counted, both inside and outside the cage, were taken as near the top of the cage as possible, so that differences in the diameter of the tree, bark thickness etc. inside and above the cage were minimized. This was the ideal condition, which was not completely realized; exceptions will be noted.

Results

The results from these counts are given in Table 1. The data for some of the trees are incomplete because it was not possible to make the necessary counts, due to lack of time. The larval count for K1-2 inside the cage was arbitrarily increased from 203 to 300, because on the basis of other counts made it was obviously abnormally low. This was because the count was made at only 5 feet above the base, at which height the brood is almost always smaller than at 15 feet above the base, where the emergence count was taken.

The effect of the clerids, aided to a limited extent by other natural enemies of the scolytid, is more clearly shown by Figs. 9 and 10. In Figure 9 the D. brevicomis brood reduction from the large larval stage to emergence inside the cage is compared with the brood reduction outside the cage on trees J-4, T-6, K2-I and K1-II. The letter J signifies trees killed in 1926 and the letter K trees killed in 1927. Figure 9 shows a striking difference in brood mortality inside the cage where the clerids and other large predators were excluded, and outside, where clerids were quite abundant. Figure 10 shows the effect of the predators on the total emergence.

Tree K3-II received treatment different from the others. The trunk was separated into halves longitudinally by shaving two smooth strips on opposite sides of the tree, caging each half with a four-foot width of fine-mesh screen and tacking it with wooden strips, so that the insects from one side could not get into the other. The top and bottom of each side were fitted closely around the trunk and made insect-tight by the use of cotton batting (see Fig. 11).

An equal number of D. brevicomis adults (4,000) was released in each side of the cage, and 50 T.n. adults were released on one side, the other being kept free of predators.

This gave three different areas for comparison on the same tree—the south side of the tree with no predators, the north side with 50 T. nigriventris adults (about one per square foot), and above the cage the number of clerids found naturally. The results show the effect of the clerids on the emergence of D. brevicomis, but the concentration of clerids above the cage was less than is usually found, so that the differences are not so great as they might have been.

While the effect on brood reduction shown in the preceding cannot be credited entirely to T. nigriventris, analyses of the bark contents show that this clerid is undoubtedly the principal factor. Since the parasites are so small that they were not kept out of the cages by the screen, the only insects beside the clerids that effected the brood reduction outside the cage, and not inside, are the ostomid, T. virescens var. chlorodia, and possibly cerambycids. As the cerambycids affect only the very small larvae while in the phloem, their effect would not show up in brood reduction—because no counts were made in this small larva stage—though it would in emergence. The ostomid is a factor of some importance, but the bark counts showed that it was only about one-quarter as abundant as the clerid; and as it feeds to some extent on clerids and other beneficial insects as well as on the D. brevicomis broods, it is of much less importance than the clerid.

Referring again to Table 1, the difference in the number of clerids found per square foot on different trees is quite remarkable, varying from two on I-5 to 37 on K2-I. The reason for this is not known, but it is believed that it may be due to the nature of the time of attack of D. brevicomis. Apparently the first tree to be attacked within a local area attracts most of the clerids that are near, and consequently it has a greater number than trees attacked soon afterward. This holds true for all the caged trees on which the exact time of attack was known. It has been noticed that the heaviest concentration of clerids found has been on the caged trees. Evidently there is something about the method of starting attack or the large number of D. brevicomis used that attracts a greater number of clerids than are found on naturally-attacked trees. In spite of this, the number of clerids found with the D. brevicomis broods in trees normally attacked averages about as high as it does in the caged trees, and the effect of T. nigriventris under natural conditions is probably as great as has been shown for the caged trees. This belief is supported by emergence counts from hundreds of square feet of bark, from which it is found that the emergence from normally-attacked trees averages about the same as the emergence from the uncaged part of caged trees.

Aside from the difference in the emergence of D. brevicomis inside and outside the cages, whihh may be partly due to other factors, it is apparent that the large number of clerids found in infested bark outside the cages would have a pronounced effect in reducing the bark-beetle broods. From the feeding studies it was found that the average T. nigriventris larva destroyed more than .5 D. brevicomis per day; so that from 5 to 37 T. nigriventris feeding for a period of at least two or three weeks would be a very important factor in brood reduction.

This beneficial effectwwould be continued in the adult stage, and it is evident that trees from which the *D. brevicomis* emergence is only about twice as great as the emergence of clerids would provide enough predators to more than account for the barkbeetles that emerged from them, since feeding studies showed that each *T. nigriventris* adult might easily destroy 25 or 30 *D. brevicomis* adults.

Table I

Effect of *T. nigriventris* on *D. brevicomis* Broods

		Inside Cage					Above Cage					
					Decrease Db.Broods						Db.brood Mortality	
Tree No.	Stage	Basis #sq.ft	Db.per sq.ft.	Tn.per sq.ft.	No.	%	Stage	Basis sq.ft.	Db.per sq.ft.	Tn.per sq.ft.	No.	%
1926												
J-4							L&P	1	443			
	Em.	8	133	5			Em.	7.8	42	22	401	90
J-5							L.$\frac{1}{4}$-$\frac{3}{4}$	1	196	2		
	L-NA	1	336	1			L-NA	1	98	2		
							Em.	5.6	36	2	62	63
J-6	L-NA	1	112	0			L&P	1	238			
	Em.	6.5	73	1.3	39	35	Em.	1	50	5	188	79
1927												
K2-I	L,few P	7.8	365	0			L,few P	2	309			
							L,P, NA	4.4	229			
	A-Em.	2	247	0	118	32.2	A-Em.	4	76	37	233	75
K1-2	L	6	300*	1			L, P	6.4	220	15		
	Em.	5.5	191		109	36.3	Em.	5.0	54		166	75
K-3						Sside No Tn.	Em.	2	230			
						Nside 50 Tn.	Em.	2	212			
						Outside Normal	Em.	2	151			

*Estimated; actual no. 203

Protecting *T. nigriventris* on Control Operations

This phase of the study, which is of most importance from the economic standpoint, is far from complete, and should be the object of further study. At present two recommendations can be made on the basis of certain known facts concerning the habits of this clerid.

1. In general, control work should not be directed against the summer-generation *D. brevicomis* trees because of the large number of clerids on these trees.

This concentration of *T. nigriventris* on the first-generation *D. brevicomis* trees was suspected because of the "hangover" until the following spring of a small percentage of the larvae from the first-generation trees and a large percentage of the larvae from second-generation *D. brevicomis* trees. Because of this habit we have during April to July of any year clerids emerging from all the *D. brevicomis* trees killed the preceding summer (see Life History Chart, Fig. 7).

To check this point and determine how the number of clerids compared in the different generations of *D. brevicomis* trees, over 500 square feet of infested bark was shaved up and all the clerids counted. Most of these counts were made during 1926 and 1927.

The results are given in Table 2, and the difference in abundance of clerids for the three generations is shown graphically in Fig. 12. This proportion is also shown roughly in Life History Chart, Fig.7. Since the results obtained in 1927 check very well with the 1926 results, it is probable that this proportion is fairly constant. The counts from the third-generation trees do not have as good a basis as the other two generations, but check very well with what we should expect from the life history studies.

These data are sufficient to prove the danger of general control work on the early summer trees, which may have as many as 30 clerids per square foot for the entire tree, or up to 50 in a single square foot. Since such large numbers of clerids would more than account for the number of *D. brevicomis* that emerged from these trees, it seems evident that artificial control work as usually performed--falling the trees and burning the bark--would do as much harm as good, and probably more harm than good on many of the trees.

The only summer control work that was done on the Southern Oregon-Northern California Project proved very ineffective in comparison with the work on the overwintering broods and the destruction of a large number of clerids--which constitute the most effective check on the increase of the *D. brevicomis* missed in the control work--was probably a major reason.

In general, then, artificial control work as now practised should be concentrated on trees containing the overwintering *D.b.* broods, since such trees contain the smallest number of *T. nigriventris*.

Table 2

Abundance of T. nigriventris by Generations
Normal Broods Outside of Cages - Before Migration

Generation I

	Basis				
	No. Trees	No. Sq.Ft.	Total # T.n.		T.n. per sq.ft.
1926	5	155.0			11.60
1927	10	191.8	2332		12.16
Total	15	346.8	[illegible]	Av.	11.88

Generation II

1926	6	114.0			6.50
1927	4	23.5	136		5.79
Total	10	137.5		Av.	6.14

Generation III

1922	1	18	71		3.94
1926	1	15.5	40		2.58
1927	2	6	16		2.66
	4	39.5	127	Av.	3.22

2. The bases of infested trees should be protected from control fires in order to save any clerid larvae that might have migrated before the trees were treated.

This migratory habit of the mature larvae has been known for a number of years, and the writer, during 1926 and 1927, determined the approximate percentage that migrates for each of the three D. brevicomis generations found at Northfork, Calif.

This was found by making comparative counts of the number of clerids in a square foot of bark before and after pupation. The results are given in the following table (3) and shown graphically in Figs.13 & 14. No reason can be given for the variation in the number that migrated--from 44 to 93 per cent. It is probable that this would vary for different years, and it is known to vary for different trees in the same year. The data may be inadequate as a basis for comparing the amount of migration by generations, but are sufficient to show that a very large percentage of the clerids from the three-generation trees do migrate.

These mature larvae pupate in the outer bark at the base of the tree near, or from one to four inches beneath, the surface of the ground litter, in pieces of bark, twigs and other litter, and in the soil itself. Many of the larvae probably crawl some distance from the base of the tree, as the total number found there is never sufficient to account for the total number that must have migrated. As many as 125 prepupal larvae have been found at the base of a single tree.

The number of clerids saved by protecting the bases of the treated trees depends on the abundance of the clerids and the stage of the brood at the time the tree is treated. Since none of the larvae migrate~~s~~ normally until mature, it is evident that the more advanced the brood is at the time of treating, the greater the percentage of clerids saved. On trees in which the D. brevicomis broods had reached the adult stage most of the migration would have occurred and a large percentage of the clerids would be saved.

Table 3

Migration of T. nigriventris

	Basis		T.n. per sq.ft.		Decrease per Sq.Ft.	
	Trees	No.sq.ft	Before-Migration	-After	No.	%
Gen. I Before migration	15	346.8	11.88			
After migration	2	16.		6.6	5.28	44.4
Gen. II Before mi.	10	137.5	6.14			
After mi.	9	23		.856	5.284	86.2
Gen. III Before mi.	1	33.5	3.32			
After mi.	14	88.5		.23	3.09	93.1

Suggestion for Further Studies on Protecting T. nigriventris on Control Operations

The mobility of the clerid larvae at all stages and the migratory habit in the mature larval stage suggests the possibility of saving a large proportion of the clerids on control operations.

This could probably be accomplished by falling, or falling and peeling the infested trees and leaving them for certain periods before burning the bark. The length of this period would depend largely on the stage of the brood when the tree was peeled. It is believed that a method could be worked out by which most of the clerids could be saved without sacrificing the efficiency of the D. brevicomis destruction. The principal difficulty would be to develop a method that would be economically practicable.

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SUMMARY

This report assembles, in preliminary form, the results of five years of study of the natural insect enemies of the western pine bark beetle, supplemented by a study of the notes, published and unpublished, of other workers who have contributed to our knowledge of this subject.

Preliminary studies showed that parasites are of much less importance than the predators and for that reason very little work has been done on them. There are a few pteromalid (Hymenoptera) parasites and at least one dipterous parasite which are commonly associated with *D. brevicomis* and which are probably parasitic upon it, but little is known of their habits or their importance except that it is not very great.

Although there are a great many more or less typically predaceous insects associated with *D. brevicomis* few of them are of real importance in its control. The habits of the larvae, of this bark-beetle, which develop out in the bark rather than under the bark as so many of its associates do, limits the predators on this stage to the bark boring forms which can tunnel about in the bark in their search for prey. There are only three predators which are not affected by this limitation, the clerid, *Thanasimus nigriventris*, the ostomid, *Temnochila virescens*, *chlorodia*, and the colydiid, *Aulonium longum*. Of these the colydiid was found to be of little importance, which leaves the clerid and the ostomid as the only effective predators of the western pine beetle.

The life history and habits of *T. virescens, chlorodia* were worked out in some detail. It was found to be of some importance in the natural control of *D. brevicomis* but its value is lessened by the fact that it feeds on beneficial insects as well as on the injurious barkbeetles.

The clerid, *Thanasimus nigriventris*, is undoubtedly the most important insect enemy of the western pine beetle. When associated with *D. brevicomis* it feeds almost exclusively on this scolytid, it has never been reported as feeding on beneficial insects and it is about four times as abundant as the ostomid, its closest competitor.

A large part of the time spent on this study was devoted to a detailed study of the life history and habits of this clerid (*T. nigriventris*). and to a study of its importance and the possibilities of increasing its effectiveness by modifications in the methods used in the control of *D. brevicomis*. The following points were brought out in this study:

1. *T. nigriventris* is closely associated with *D. brevicomis* throughout its life history and is predaceous on it both the larval and adult stages.

2. In abundance it varies from 2 or 3 per square foot of <u>D. brevicomis</u> infested bark to as many as 50 per square foot. They are most abundant on the first generation (<u>D. brevicomis</u>) trees and least abundant on the over-wintering trees.

3. It was found that where <u>T. nigriventris</u> was abundant the brood mortality of <u>D. brevicomis</u> was more than twice as great as where the clerids were excluded.

4. Two suggestions can be given for protecting clerids on control operations.

   a. In general, control work should not be directed against the summer-generation <u>D. brevicomis</u> trees because the clerids are usually 2 or 3 times as abundant on these trees as on late summer or winter generation trees.

   b. Because a large percentage of the mature clerid larvae migrate to the base of the tree the bases of these trees should be protected from control fires.

5. The mobility of the clerid larvae in all stages and the migratory habit in the mature stage suggests the possibility of saving a much larger proportion of the clerids on control operations by treating only trees from which the broods are about to emerge or by hastening the migration of the clerids by felling or falling and peeling the infested trees a few days before burning the bark.

Fig. 1 Relation of *Graphisurus spectabilis* to the Emergence of *D. brevicomis*

FIG. I

RELATION BETWEEN AMOUNT OF CERAMBYCID WORK AND D. BREVICOMIS EMERGENCE AVERAGES FOR 4 TREES

■ - PERCENT OF INNER BARK WORKED BY G. SPECTABILIS

□ D. BREVICOMIS EMERGENCE

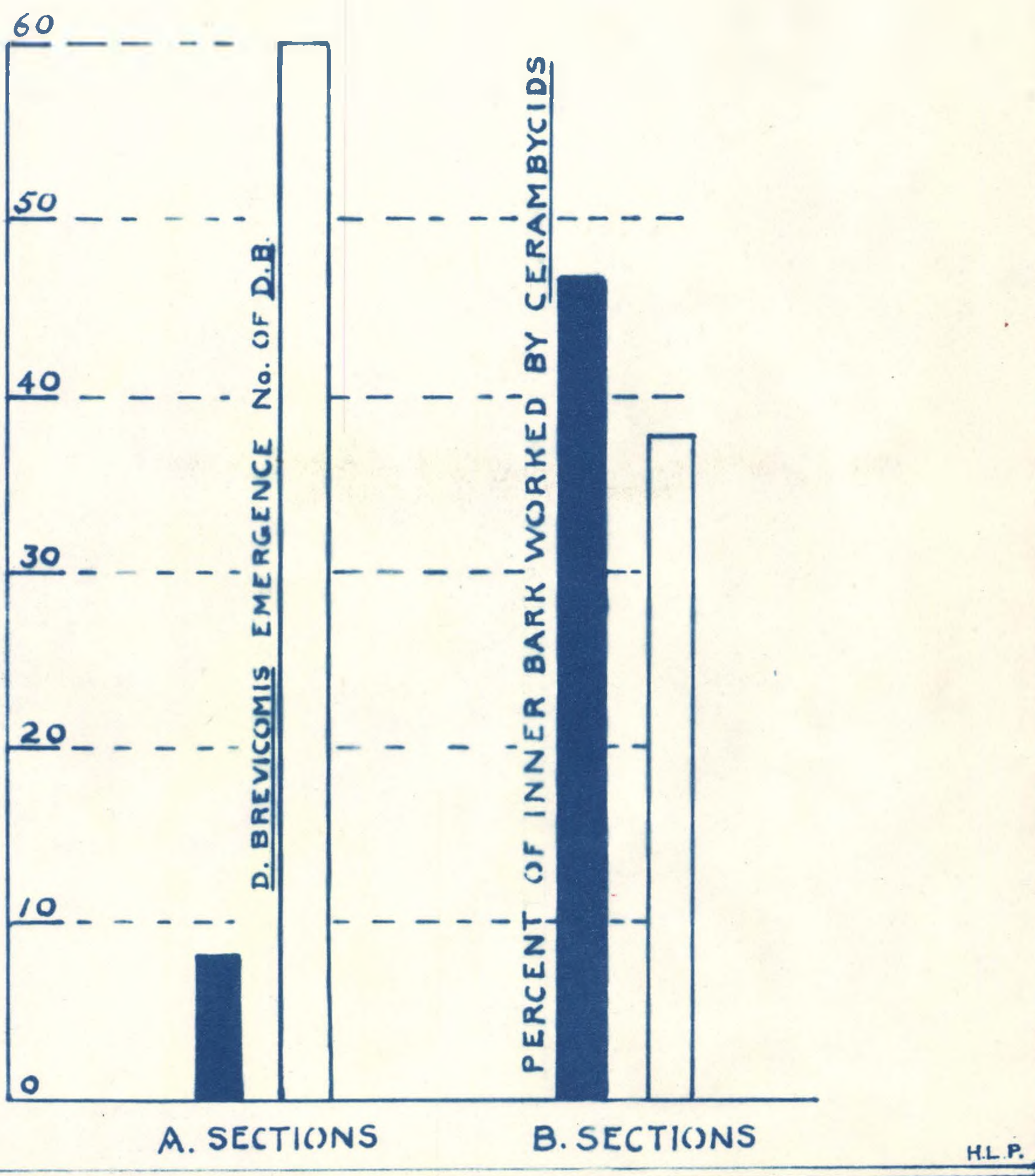


Fig. 2 Pupal cells of *Temnochila virescens* var. *chlorodia* in yellow pine bark which had been infested with *D. brevicomis*. The small round apertures are the emergence and ventilation holes of *D. brevicomis*. Slightly enlarged. Photo by Patterson.

Fig. 3 Newly-laid *T. nigriventris* eggs on yellow pine bark.

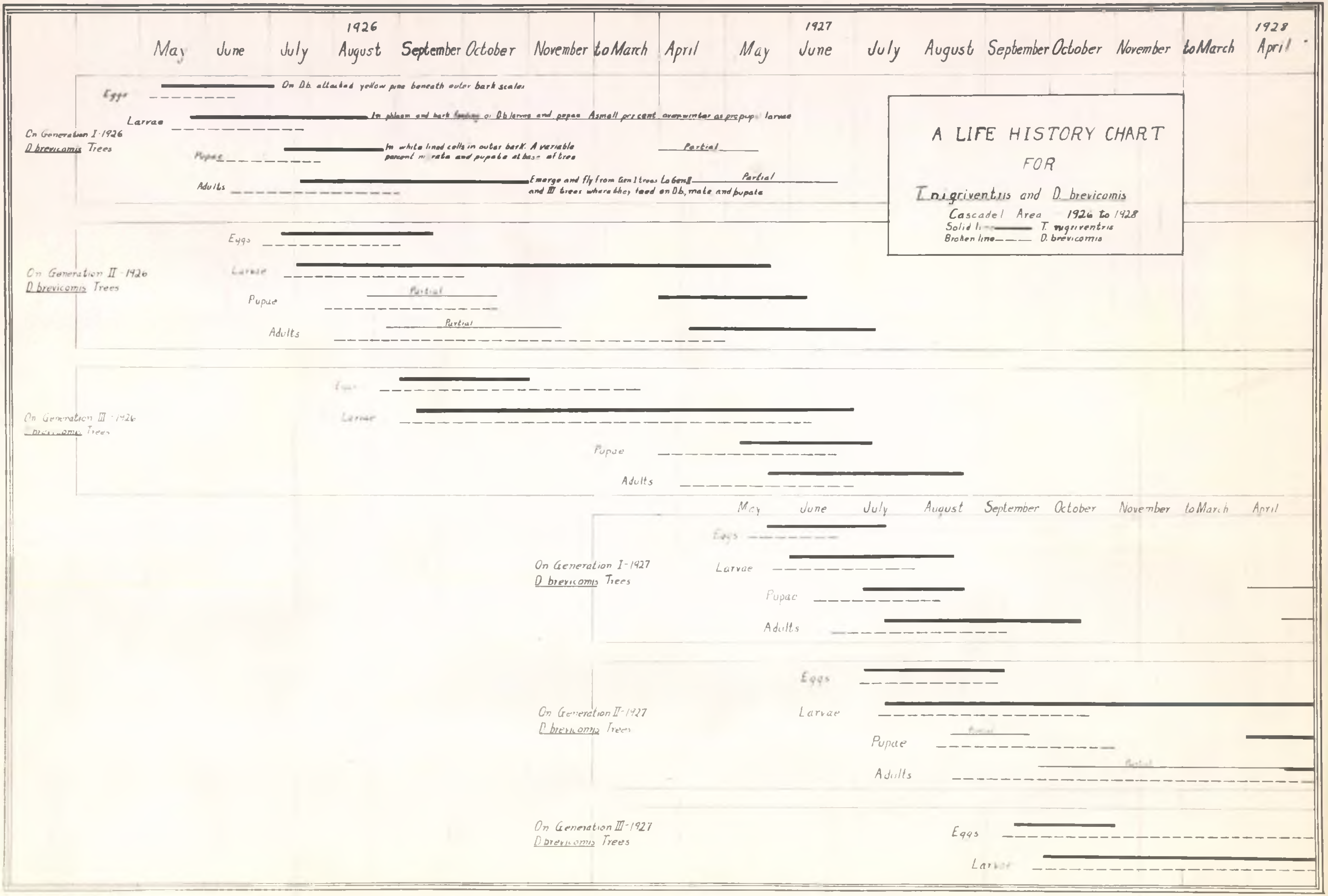
Enl.abt.3x
Photo by Miller and Person.

Fig. 4 *T.nigriventris* egg shells from which larvae have emerged; as found on bark scale of yellow pine tree infested with *D.brevicomis*.

Enl. 3x Photo by Patterson

Fig. 5 Pupal cells of _T. nigriventris_ in
bark from base of yellow pine tree
killed by _D. brevicomis_.

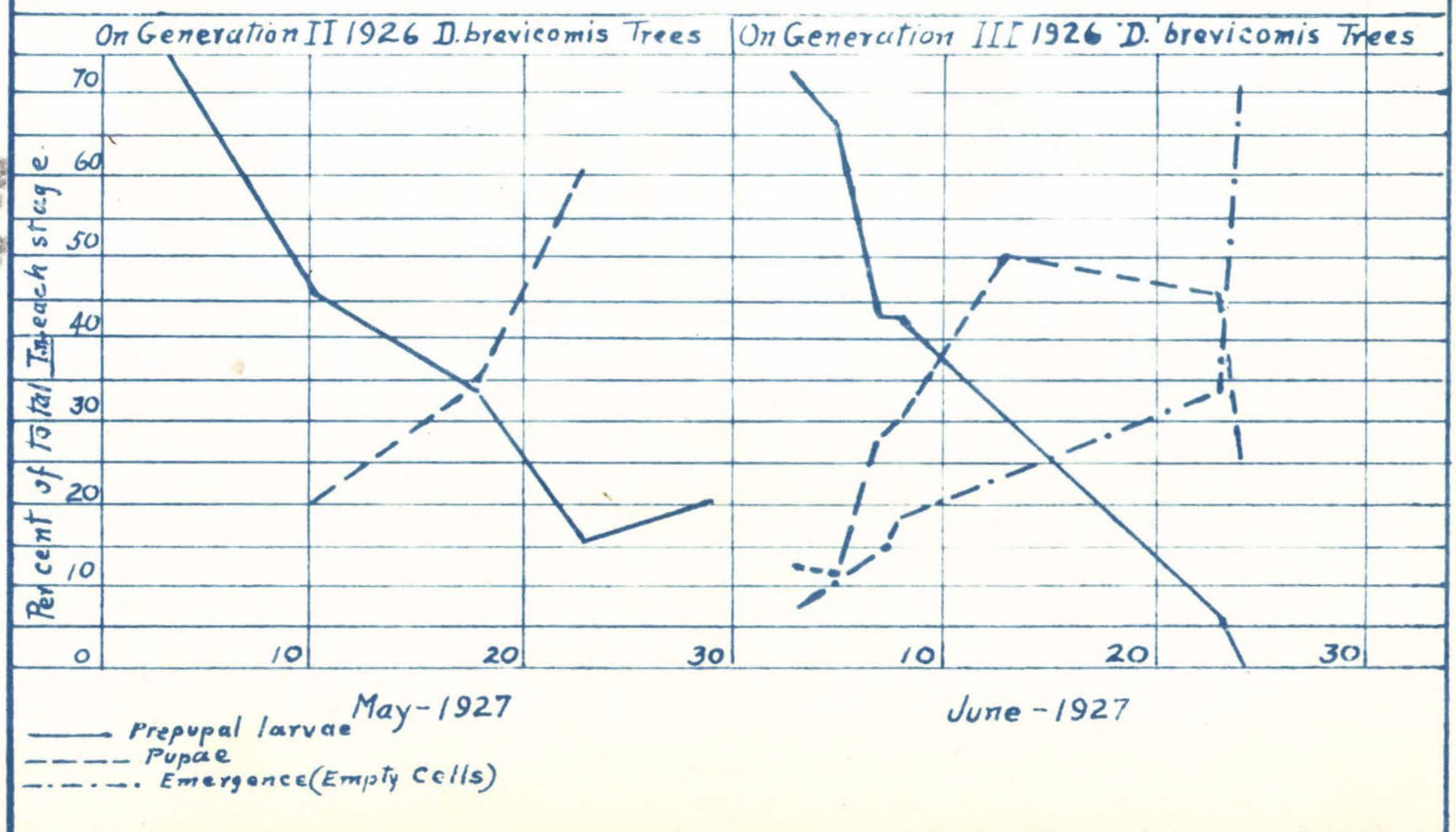
Slightly enlarged
Photo by Patterson.



1926
May June July August September October November to March April May June July August September October November to March April
1927
1928
A LIFE HISTORY CHART
FOR
T. nigriventris and D. brevicomis
Cascadel Area 1926 to 1928
Solid line T. nigriventris
Broken line D. brevicomis
On Generation I - 1926
D. brevicomis Trees
Eggs
On Db. attacked yellow pine beneath outer bark scales
Larvae
In phloem and bark feeding on Db larvae and pupae. A small per cent overwinter as prepupal larvae
Pupae
In white lined cells in outer bark. A variable percent migrate and pupate at base of tree
Partial
Adults
Emerge and fly from Gen I trees to Gen II and III trees where they feed on Db, mate and pupate
Partial
On Generation II - 1926
D. brevicomis Trees
Eggs
Larvae
Pupae
Partial
Adults
Partial
On Generation III - 1926
D. brevicomis Trees
Eggs
Larvae
Pupae
Adults
May June July August September October November to March April
On Generation I - 1927
D. brevicomis Trees
Eggs
Larvae
Pupae
Adults
On Generation II - 1927
D. brevicomis Trees
Eggs
Larvae
Pupae
Partial
Adults
Partial
On Generation III - 1927
D. brevicomis Trees
Eggs
Larvae

Fig. 6

Comparative Abundance of Different Stages
in Development of
Thanasimus nigriventris
North Fork, California -1927



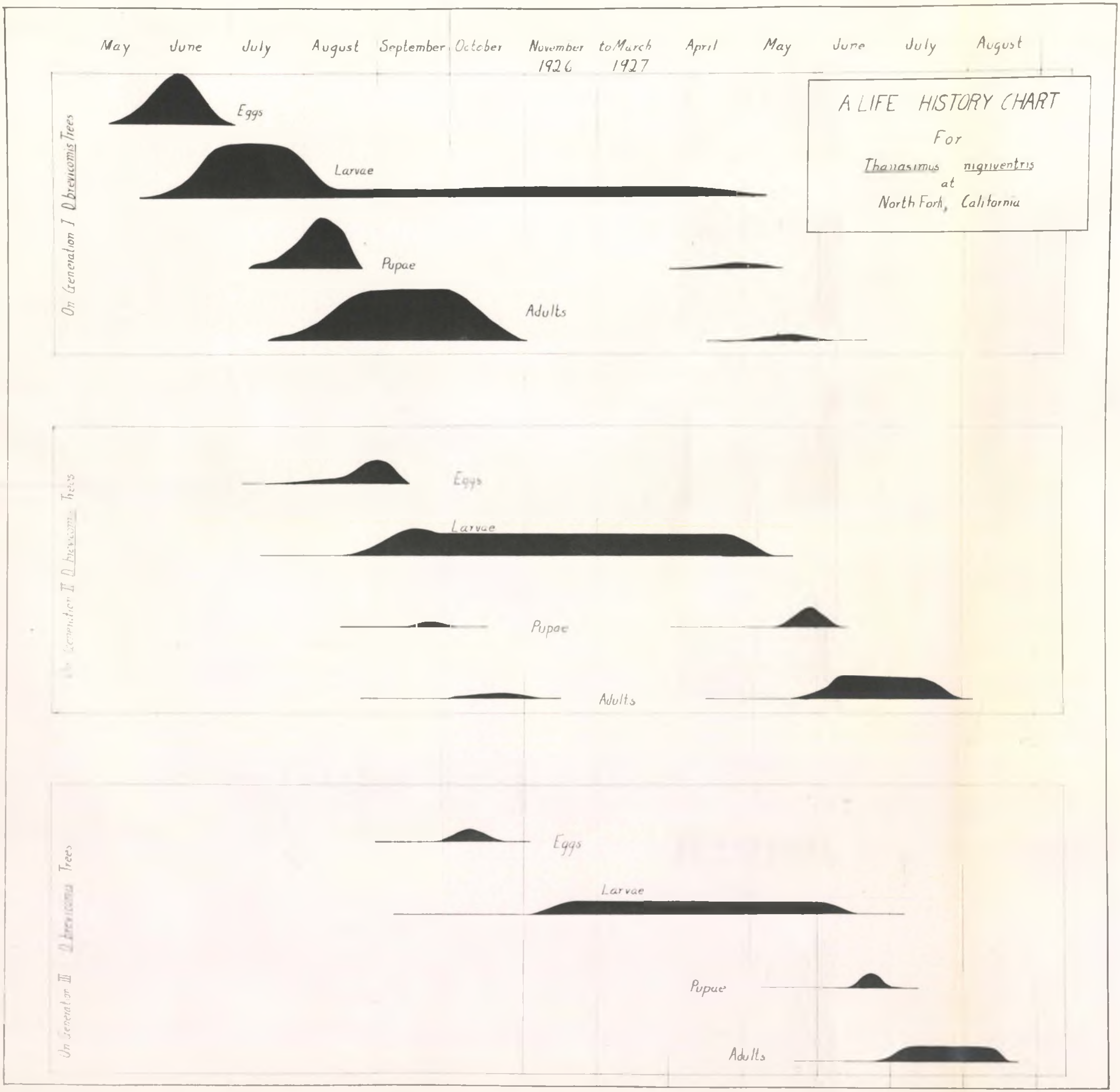
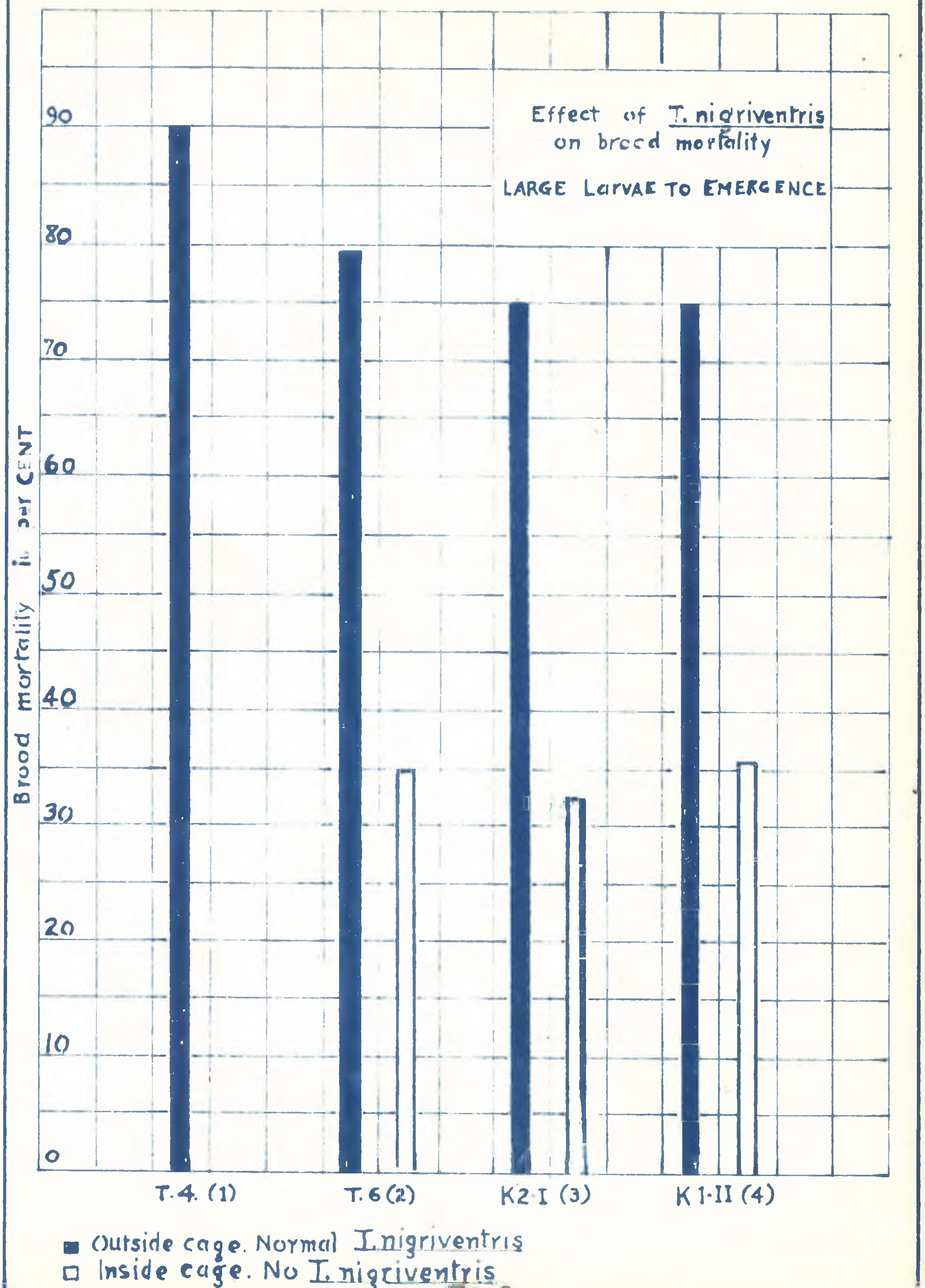

May
June
July
August
September
October
November 1926
to March 1927
April
May
June
July
August
A LIFE HISTORY CHART
For
Thanasimus nigriventris
at
North Fork, California
On Generation I Q. brevicomis Trees
Eggs
Larvae
Pupae
Adults
Eggs
Larvae
Pupae
Adults
Eggs
Larvae
Pupae
Adults

Fig. 7

Fig. 3 Type of cage used in Cascadel experiments to determine the importance of T. nigriventris; yellow pine bark infested with D. brevicomis was put in the cage. Photo by Miller.


6166


Effect of T. nigriventris on brood mortality
LARGE LARVAE TO EMERGENCE
Brood mortality in per CENT
90
80
70
60
50
40
30
20
10
0
T.4. (1)
T.6 (2)
K2 I (3)
K 1-II (4)
Outside cage. Normal T. nigriventris
Inside cage. No T. nigriventris

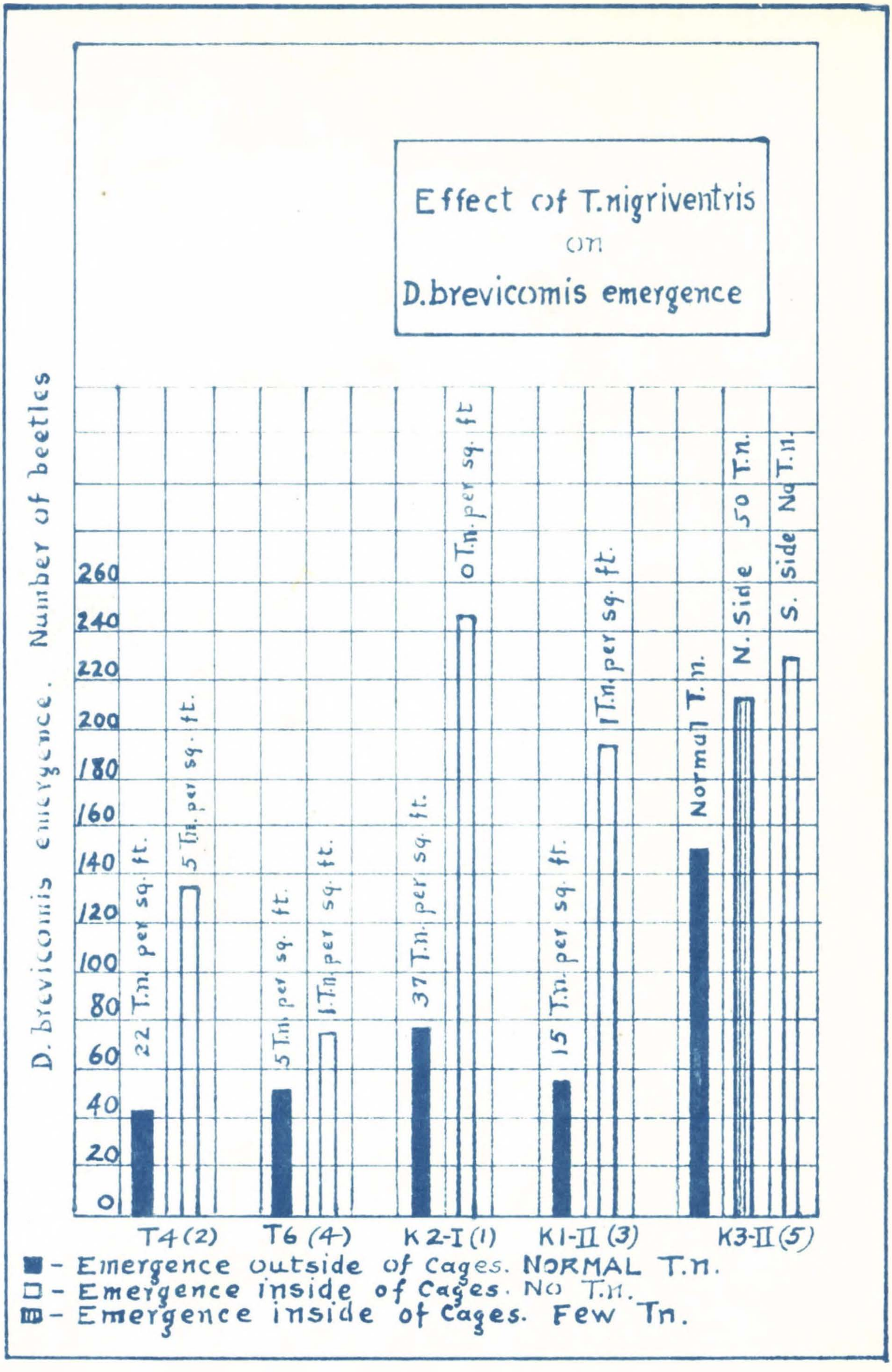
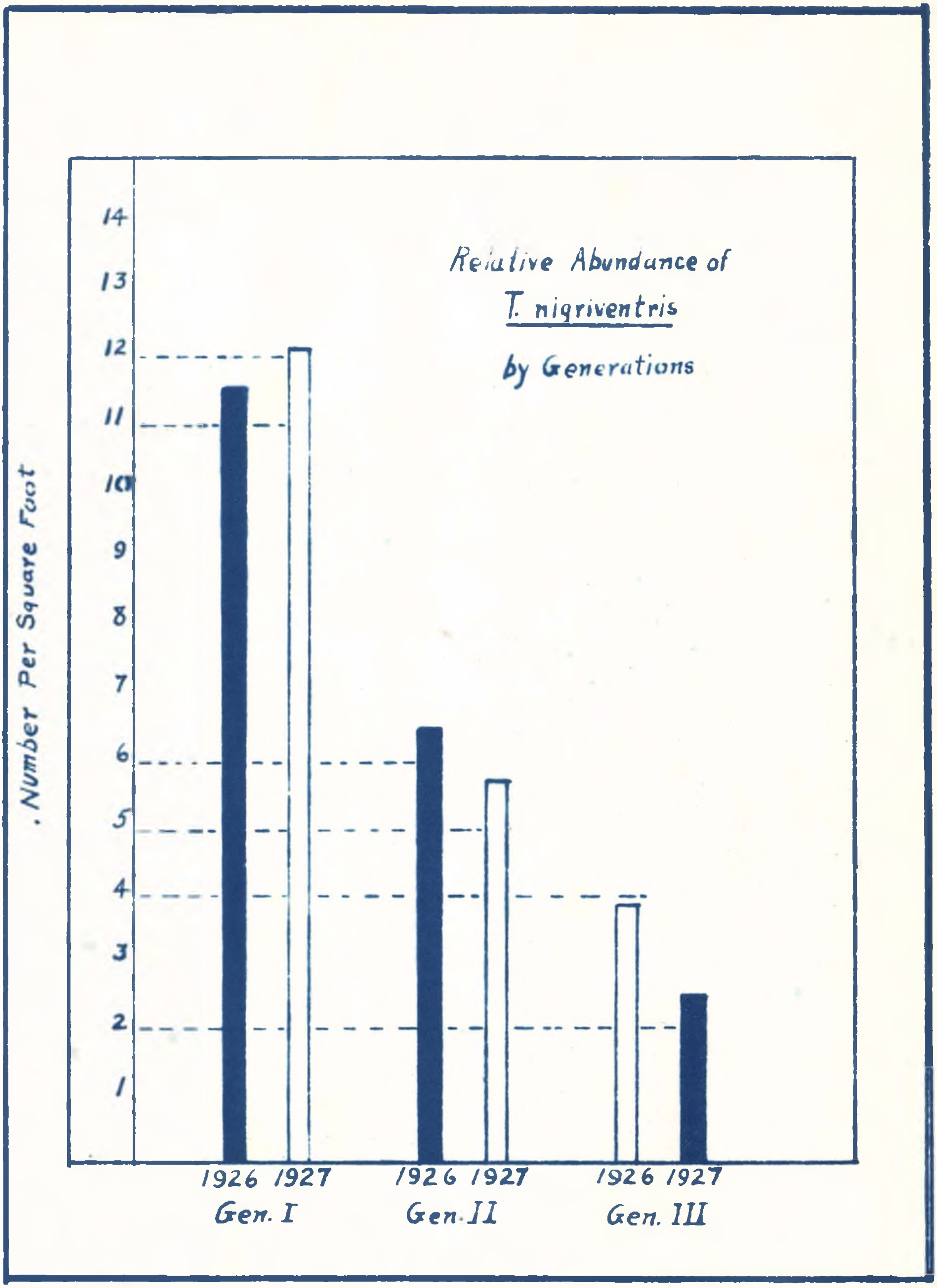

Effect of T.nigriventris
on
D.brevicomis emergence
D. brevicomis emergence. Number of beetles
0
20
40
60
80
100
120
140
160
180
200
220
240
260
22 T.n. per sq. ft.
5 T.n. per sq. ft.
5 T.n. per sq. ft.
1 T.n. per sq. ft.
37 T.n. per sq. ft.
0 T.n. per sq. ft
15 T.n. per sq. ft.
1 T.n. per sq. ft.
Normal T.n.
N. Side 50 T.n.
S. side No T.n.
T4 (2)
T6 (4)
K2-I (1)
K1-II (3)
K3-II (5)
- Emergence outside of Cages. NORMAL T.n.
- Emergence inside of Cages. No T.n.
- Emergence inside of Cages. Few Tn.

Fig. 10

Fig. 11 Double cage used on Tree #K5-II for *T. nigriventris* experiment at Cascadel. *D. brevicomis* adults only were put in one side of the cage while both *D. brevicomis* and *T. nigriventris* were put in the other side.


6529



Relative Abundance of
T. nigriventris
by Generations
Number Per Square Foot
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1926 1927
Gen. I
1926 1927
Gen. II
1926 1927
Gen. III

Fig. 12.

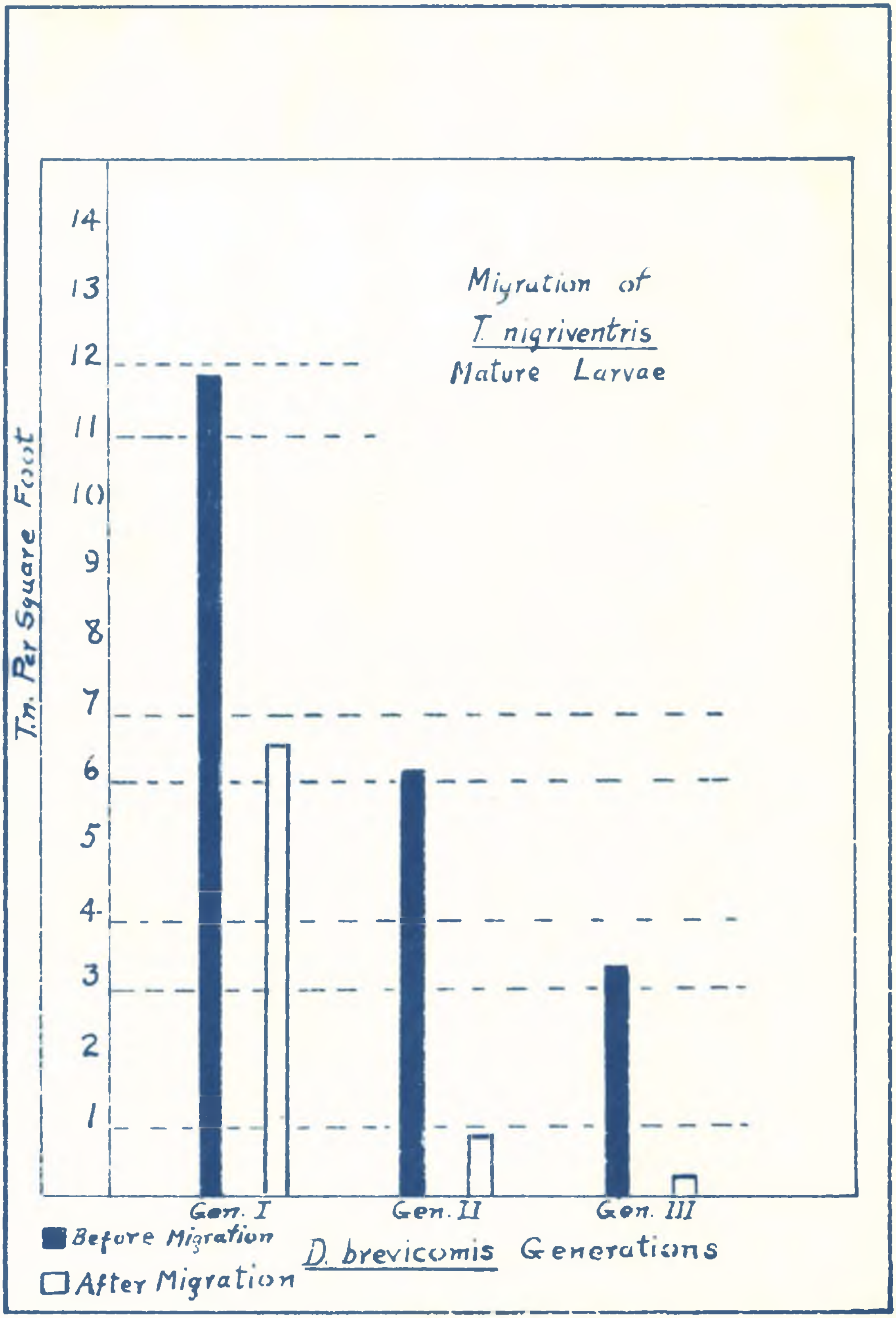

Migration of
T. nigriventris
Mature Larvae
T.n. Per Square Foot
14
13
12
11
10
9
8
7
6
5
4
3
2
1
Gen. I
Gen. II
Gen. III
Before Migration
After Migration
D. brevicomis Generations

Fig. 16

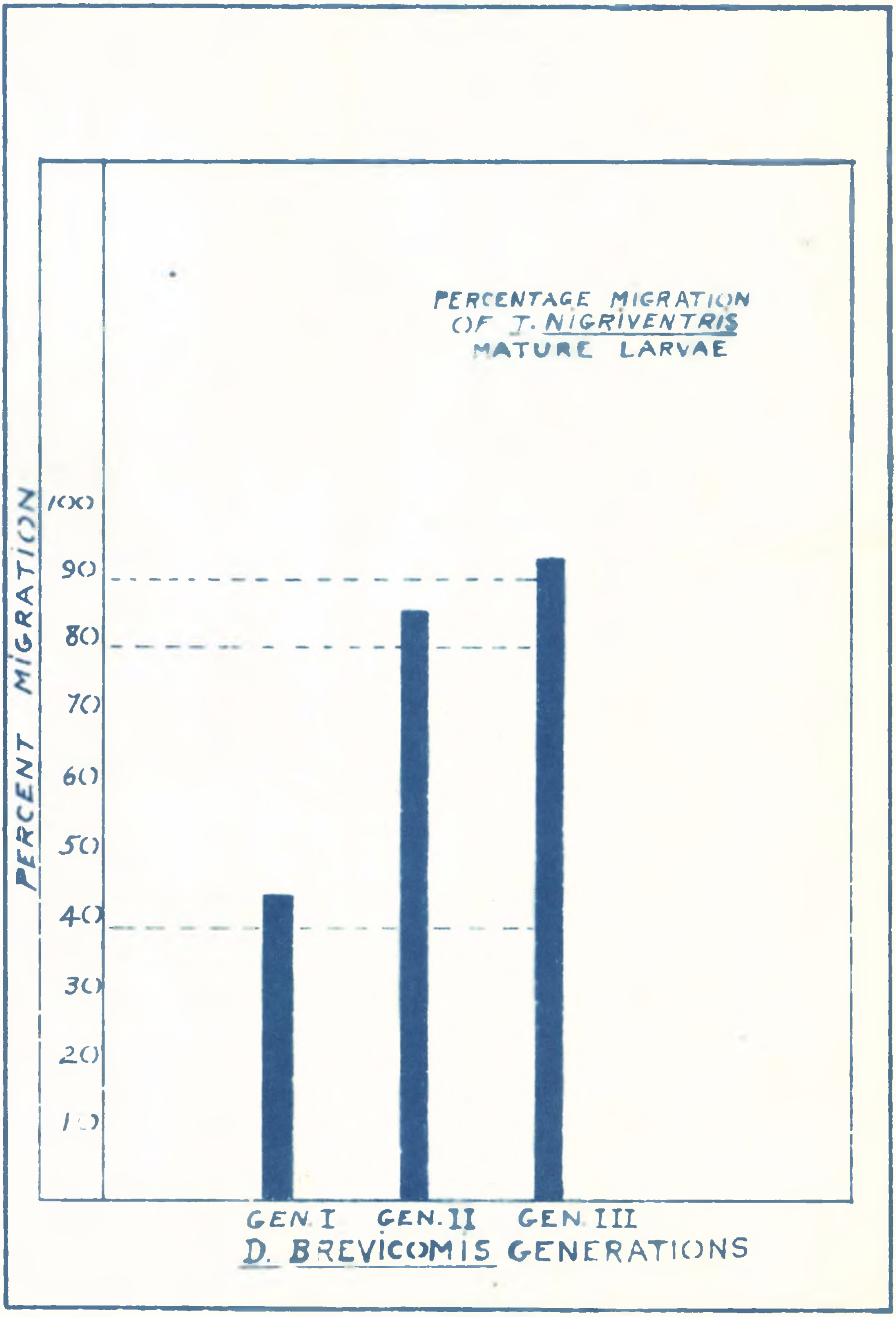

PERCENTAGE MIGRATION
OF T. NIGRIVENTRIS
MATURE LARVAE
PERCENT MIGRATION
100
90
80
70
60
50
40
30
20
10
GEN. I
GEN. II
GEN. III
D. BREVICOMIS GENERATIONS

Fig. 14